frontiers in Virtual Reality

TYPE Hypothesis and Theory
PUBLISHED 13 May 2026
DOI 10.3389/frvir.2026.1818469

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OPEN ACCESS

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RECEIVED 26 February 2026
REVISED 30 March 2026
ACCEPTED 09 April 2026
PUBLISHED 13 May 2026

CITATION
Hechavarria-Hernandez JR, Vasquez-Cevallos L and Smarandache F (2026) Neutrosophic technarrative architecture for symbolic–emotional evaluation of virtual architectural spaces in VR.
Front. Virtual Real. 7:1818469.
doi: 10.3389/frvir.2026.1818469

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Neutrosophic technarrative architecture for symbolic–emotional evaluation of virtual architectural spaces in VR

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Virtual reality (VR) is increasingly employed to investigate human-environment interactions; however, current evaluation methods remain fragmented. Physical–functional metrics, biofeedback signals, and self-report data are frequently analyzed in isolation, leaving the symbolic–narrative dimension of architecture largely implicit. This Hypothesis and Theory article introduces the Neutrosophic Technarrative Architecture (NTA): a robust methodological framework and computational pipeline for the symbolic–emotional evaluation of virtual architectural spaces. The proposed framework integrates four core components: (1) the Neutrosophic Technarrative Model (NTM), which encodes architectural spaces through symbolic nodes such as justice, identity, hope, resistance, and eco-symbiosis; (2) immersive VR scenarios acting as controlled symbolic environments; (3) psychophysiological measures (EEG, GSR, HRV) as indicators of affective engagement; and (4) an AI-ready computational model that links symbolic design variables, biofeedback features, and user evaluations via neutrosophic inference. Rather than introducing new sensing technologies, the novelty of NTA lies in the symbolic–computational integration of existing VR and affective computing methods. We define the conceptual structure of NTA, formulate testable hypotheses, and provide a reproducible methodological blueprint—supported by open-source Python implementations—for multimodal analysis. We demonstrate that NTA (a) offers a systematic pipeline for connecting symbolic design intentions with measurable VR experiences, (b) employs neutrosophic representation to quantify ambiguity and indeterminacy in user responses, and (c) enables predictive modelling that transcends traditional self-report-only approaches. This work establishes a foundational research agenda at the intersection of VR user experience, neuroarchitecture, and ethically oriented design.

KEYWORDS
AI in design, biofeedback, human-computer interaction, neuroarchitecture, neutrosophic logic, presence theory, symbolic architecture, virtual reality

Highlights

- Integration of Symbolic Architecture and VR: Proposes the Neutrosophic Technarrative Architecture (NTA), a framework that bridges symbolic-narrative design with immersive VR and biofeedback.

- Neutrosophic Uncertainty Quantification: Implements Neutrosophic Logic (T, I, F) to quantify "Indeterminacy," capturing cognitive dissonance and emotional uncertainty that traditional linear models fail to detect.
- Expansion of Presence Theory: Extends Mel Slater's seminal Presence Theory by introducing "Symbolic Significance" as a critical third layer for evaluating architectural experience in virtual environments.
- Architectural Computational Modeling: Establishes a computational proof-of-concept demonstrating how symbolic nodes (e.g., Justice, Hope, Resistance) function as theoretical predictors of user psychophysiological response within the NTA pipeline.
- Methodological Reproducibility: Provides a fully documented Python-based pipeline and synthetic dataset to ensure the transparency and future scalability of neutrosophic neuroarchitecture research.

1 Introduction

1.1 Previous work: the technarrative model (NTM)

In previous work we introduced the Technarrative Model (NTM) for the Symbolic–Emotional Evaluation of Architectural Space, published in Neutrosophic Sets and Systems (Hechavarría-Hernández et al., 2025). That study addressed a real heritage building and proposed a neutrosophic multiperspectivist method to integrate the often-contradictory evaluations of different stakeholder groups (residents, visitors, preservationists, architects). Symbolic–emotional appraisals were expressed through neutrosophic triads ⟨T, I, F⟩ and aggregated using Ordered Weighted Averaging (OWA) operators, allowing the model to quantify tension, polarization and uncertainty across perspectives (Smarandache et al., 2025). The main contribution of NTM was a formal rubric for symbolic assessment of built spaces, demonstrating that ethical and emotional dimensions—such as belonging, conflict or exclusion—could be systematically captured and analysed in architectural case studies.

The present article builds on this foundation but shifts the focus in two crucial ways. First, instead of evaluating a single existing building through expert and community judgments, we concentrate on immersive virtual environments that can be deliberately designed, manipulated and iterated as experimental stimuli. Second, rather than restricting data to self-reports from multiple stakeholder groups, we integrate biofeedback and behavioural measures at the individual level, and we embed the model within a broader virtual-reality pipeline involving AI-based analysis. We refer to this extended framework as the Neutrosophic Technarrative Architecture (NTA).

1.2 Virtual reality and neuroarchitecture for architectural experience

Virtual reality (VR) has become a central tool for studying how people experience architectural space, enabling controlled exposure to complex environments while recording behavioural and physiological responses. In parallel, neuroarchitecture has emerged as a field that explicitly links design with brain and bodily responses, using tools such as EEG, eye tracking and other biometrics to understand how built environments influence cognition, emotion and behavior (Abbas et al., 2024; Fernandes and Chivanga, 2025). Recent reviews emphasise that neuroarchitecture holds strong promise for enhancing wellbeing and mental health, but also highlight the lack of unified methodological frameworks that can guide design practice in a systematic way (Jaberi et al., 2026).

Within this landscape, several strands of work are particularly relevant. Systematic reviews on VR and electroencephalography in architectural design show that immersive VR combined with EEG can reveal how geometry, light and spatial configuration modulate affective and aesthetic responses, but also report large heterogeneity in protocols, measures and analysis pipelines (Taherysayah et al., 2024). Moreover, recent science mapping and bibliometric analyses confirm an exponential growth of VR/AR integration within the AEC industry, yet reveal that current applications remain largely focused on technical efficiency rather than human-centric design outcomes (Sornoza-Parrales et al., 2025). Other overviews of neuroarchitecture and the built environment similarly conclude that, although many empirical studies exist, there is still a gap between experimental findings and actionable design strategies that can be reused across projects (Moura et al., 2025).

Crucially, the success of these applications depends on the 'sense of presence'—a psychological state recently redefined as a multidimensional phenomenon shaped by narrative structure and socio-cultural context, rather than purely technical resolution (Triberti et al., 2025). This shift is essential for the AEC industry, where research now suggests that the perceived practicality of VR varies significantly across project lifecycles—with higher value attributed to iterative design and stakeholder engagement rather than static planning (Fridkin et al., 2025). By reconciling these findings, urban and architectural design workflows can leverage VR not merely as a visualization tool, but as an interactive platform for informed decision-making and enhanced stakeholder participation (Ali et al., 2025; El-Shimy and Amany, 2015).

1.3 VR biofeedback and adaptive virtual environments

At the same time, VR–biofeedback research has grown rapidly. Scoping reviews on VR-supported biofeedback report that coupling VR with physiological measures (e.g., heart rate variability, skin conductance) can enhance motivation, immersion and user experience, yet they call for clearer methodological standards (Lüddecke and Felnhofer, 2021; Pei et al., 2021). While studies in dynamic VR environments show that biofeedback can be used to adapt virtual spaces in real time, most implementations are technology-driven and lack grounding in explicit models of architectural symbolism (Champion and Dekker, 2011). Furthermore, while modern systems utilize physiological data to tailor experiences, the conceptual frameworks for interpreting how specific environmental configurations translate into meaningful human states remain underdeveloped (Higuera-Trujillo et al., 2021; Li T. et al., 2025).

1.4 Symbolic–emotional dimensions of architecture in VR

Experimental and review articles have begun to link interior design and biometrics in immersive VR, arguing that neuroscience-informed design can create spaces that support comfort, attention, and emotion regulation (Albayrak-Kutlay and Bengisu, 2025). Furthermore, recent research suggests that intentionally designed restorative environments can serve as "adjunctive therapies" when integrated with digital health ecosystems, fostering physiological homeostasis and improving value-based healthcare outcomes (Bulaj et al., 2025). A comprehensive systematic review of neuroimaging techniques in architectural spaces identifies a paradigm shift from intuition-driven to evidence-based design, noting that while electroencephalography (EEG) and VR are increasingly paired to track dynamic emotional states, the field currently suffers from a lack of multimodal validation and standardized longitudinal protocols (Li N. et al., 2025).

Work at the boundary of architecture, biometrics, and virtual environments continues to propose multi-method approaches for design evaluation, yet researchers describe the current landscape as a "patchwork" of case-specific protocols rather than a consolidated, theory-driven methodology for symbolic and emotional assessment (Mostafavi, 2022). Furthermore, recent advancements in deep learning—specifically CNN-LSTM architectures—have demonstrated high efficacy in classifying emotional responses to spatial elements like shape and lighting (Cho et al., 2025), building upon earlier parallel research that explored AI-based EEG classification for real-time affect sensing in built environments (Kourkoumelis et al., 2025). Together, these models underscore the feasibility of real-time affect sensing, effectively bridging the gap between unconscious neurophysiological responses and architectural design optimization.

Despite these technological advances, the symbolic and narrative dimensions of architecture remain only partially operationalized in VR research. Recent systematic reviews on neuroarchitecture, immersive VR, and biometrics in design report that most empirical studies focus on low-level formal and sensory parameters (e.g., geometry, curvature, color, light, nature elements) and generic affective states, while offering limited operationalization of higher-order sociocultural or ethical constructs (Ferreira et al., 2025; Medhat Assem et al., 2023; Valentine, 2023).

Architectural and environmental psychology literature, by contrast, emphasizes that buildings and urban spaces act as carriers of meaning and identity, shaping attachment, power relations, spatial justice, memory, and experiences of inclusion or exclusion through form, materiality, and spatial sequences (Baper, 2024; Martire et al., 2026; Ries and Schwan, 2023). While this "patchwork" of case-specific protocols (Mostafavi, 2022) has yielded valuable individual findings, there remains an urgent need for a consolidated, theory-driven methodology that bridges high-level symbolic intent with the quantitative precision of VR and neuro-computational measures.

1.5 Neutrosophic logic, open gaps and aims of this article

In parallel, developments in neutrosophic logic and neutrosophic fuzzy sets offer a promising mathematical basis for dealing with the ambiguity, vagueness and inconsistency inherent in human judgments about complex environments. Neutrosophic approaches have been successfully applied in multi-criteria decision-making, where they explicitly represent degrees of truth, indeterminacy and falsity (T–I–F). Unlike traditional fuzzy sets, which often assume dependent components or ignore indeterminacy, neutrosophic sets provide a more robust mathematical framework for handling independent and conflicting variables—a necessity when dealing with the inherent ambiguities of architectural appraisal (Smarandache, 2019). Recent work argues that neutrosophic models are particularly useful when evaluators must weigh conflicting criteria under uncertainty—conditions that closely resemble how users appraise architectural spaces in terms of comfort, identity, fairness or safety (Nguyen et al., 2025). However, to date there is no integrative framework that combines neutrosophic modelling, symbolic–narrative constructs of architecture, and VR-based biofeedback experiments.

Taken together, current literature suggests three converging trends:

1. VR and biometric tools are increasingly used to study human responses to architecture, but existing protocols are fragmented and rarely grounded in explicit symbolic theories; (Jaberi et al., 2026);
2. VR-biofeedback systems show promise for affective and behavioural adaptation, yet often lack a clear conceptual link to architectural meaning or ethical dimensions such as justice and identity; (Lüddecke and Felnhofer, 2021); and
3. Neutrosophic logic offers a rigorous way to capture ambiguity and partial belief, but has not been systematically applied to the evaluation of architectural experience in VR (Garg and Garg, 2020).

This Hypothesis and Theory article responds to these gaps by introducing the Neutrosophic Technarrative Architecture (NTA): a conceptual framework that integrates (a) the Neutrosophic Technarrative Model (NTM) for symbolic encoding of architectural space (with nodes such as justice, identity, hope, resistance and eco-symbiosis), (b) immersive VR scenarios designed as controlled symbolic environments, (c) psychophysiological and interaction data as indicators of affective engagement, and (d) AI models operating on neutrosophically represented evaluations. Rather than presenting empirical data, the article aims to: (i) articulate a theory-driven architecture that connects symbolic design intentions with measurable VR experience; (ii) formulate testable hypotheses and research questions for future studies; and (iii) propose a methodological blueprint that researchers and practitioners can adapt when investigating symbolic–emotional responses to virtual architectural spaces (Llinares et al., 2025).

2 Background and related work

2.1 Virtual reality and user experience in built environments

VR has become a widely used medium for investigating how people experience complex environments, because it allows researchers to manipulate spatial variables while maintaining experimental control over exposure, navigation and viewpoint. Reviews of VR in health, training and behaviour change emphasise that immersive environments can increase presence, motivation and engagement compared to non-immersive media, but also highlight substantial variability in how "user experience" is defined and measured across studies (Carroll et al., 2021).

In architectural research, VR has been used to present controlled variations of geometry, lighting and spatial configuration. Experimental studies show that differences in curvature, enclosure or ceiling height can systematically affect reported emotions, aesthetic judgments and spatial preferences, suggesting that VR is a valid approximation for assessing affective responses to design alternatives (Shemesh et al., 2022). More recent work explores "emotional equivalence" between VR and real spaces, using EEG and heart rate variability to test whether similar neural and physiological patterns emerge across physical and virtual versions of the same environment (Kobayashi et al., 2025).

However, these approaches typically focus on relatively low-level environmental features (form, light, material, openness) and generic emotional dimensions (valence, arousal, stress), rather than on structured symbolic constructs (e.g., justice, identity, hope) that might better capture the meaning-laden nature of architectural experience.

2.2 Neuroarchitecture and psychophysiological approaches

The field of neuroarchitecture explicitly links built environments with brain and bodily responses. Conceptual and empirical work shows that architectural spaces modulate cognitive load, attention, arousal and affect, and that neuroscientific tools such as EEG, fNIRS and eye tracking can be used to probe these effects in controlled settings (Higuera-Trujillo et al., 2021). Systematic reviews focusing on VR plus EEG in architectural design report growing interest in using neural measures to evaluate design alternatives, but also emphasise heterogeneity in stimuli, protocols and analytical methods, making it difficult to compare findings or derive general guidelines for design practice (Taherysayah et al., 2024).

More recent reviews in neuroarchitecture and VR-biometrics conclude that, while many studies demonstrate sensitivity of physiological indicators to environmental changes, there is still a lack of unified frameworks that connect these indicators with explicit design intents or higher-level experiential constructs (Moura et al., 2025). This motivates the development of theory-driven architectures that treat psychophysiological measures not just as generic "stress" or "engagement" proxies, but as part of a structured model of how symbolic aspects of space are experienced and appraised.

2.3 VR biofeedback and adaptive virtual environments

A parallel line of research explores VR-based biofeedback, in which physiological signals are measured and sometimes fed back to users in real time. Scoping reviews show that VR biofeedback has been applied mainly in health and stress reduction, often reporting benefits in terms of motivation, perceived control and attentional focus compared to traditional biofeedback formats (Lüddecke and Felnhofer, 2021). Studies combining VR with heart rate, skin conductance or respiration demonstrate that these signals can guide adaptive changes in virtual environments (e.g., modifying difficulty, visual complexity or ambient features) to support training or relaxation (Klein Haneveld et al., 2023).

In architectural contexts, recent evidence has validated the use of physiological markers to quantify how intentional design modulates human affect. For instance, Mcteague et al. (2025) demonstrated that coupling Galvanic Skin Response (GSR) and Heart Rate Variability (HRV) allows for the identification of specific activation or relaxation states in response to multisensory spatial stimuli. While these findings confirm that biometic signals can effectively capture the impact of design, most implementations in VR navigation—particularly in urban regeneration or therapeutic environments—remain technology-driven. They often treat physiological data as generic indicators of stress or arousal without explicitly grounding them in a symbolic or ethical understanding of what the space represents (e.g., safety vs. threat, inclusion vs. exclusion).

This gap leaves open the question of how to integrate biofeedback into a broader conceptual model of architectural meaning. The NTA framework addresses this by evolving from purely reactive biometric monitoring toward a symbolic-narrative evaluation, where physiological "arousal" is reinterpreted through the lens of axiological nodes and neutrosophic uncertainty.

2.4 Symbolic and narrative dimensions of architectural space

Architectural theory and environmental humanities have long argued that buildings are not only functional containers, but also symbolic forms that express identity, power, memory, justice and collective values, particularly in contexts where built form functions as a carrier of collective identity and cultural narratives (Baper, 2024; Sūdžiūtė, 2023; Mukwidigwi and Naidu, 2025; Shao et al., 2025; Wang et al., 2025).

Symbolic architecture has been described as the deliberate use of form, material and spatial organisation to represent abstract ideas—such as democracy in parliaments, national identity in monuments or spiritual transcendence in religious architecture (Beggiora, 2025). Semiotic approaches to design similarly interpret architectural elements as signs that communicate cultural meanings and position users within social hierarchies and narratives, from contemporary parametricism to vernacular dwellings (Abdullah, 2025; Beggiora, 2025; Erman, 2004).

Despite this rich theoretical background, the symbolic dimension of architecture is only weakly represented in most VR and neuroarchitecture studies. Recent reviews show that immersive VR and biometric tools are predominantly used to examine responses to geometric, lighting or material parameters and broad affective categories (e.g., arousal, pleasantness, restorativeness), rather than explicit symbolic constructs such as justice, identity or hope (Albayrak-Kutlay and Bengisu, 2025; Jaberi et al., 2026; Li N. et al., 2025; Moura et al., 2025; Sözer and Yılmaz, 2025).

Existing methods rarely provide a formal way to encode these symbolic intentions into virtual scenarios, nor to analyse how they relate to multimodal measures of user experience, leading several authors to describe the current landscape as a "patchwork" of case-specific protocols rather than a consolidated, theory-driven methodology.

This gap motivates the need for a framework that treats symbolic–narrative constructs as first-class variables in experimental design—something that the proposed Neutrosophic Technarrative Architecture explicitly targets.

2.5 Neutrosophic logic and multi-criteria evaluation in design

Neutrosophic logic generalises classical and fuzzy logic by representing any statement with three components: truth (T), indeterminacy (I) and falsity (F). This allows decision-makers to explicitly model ambiguity, vagueness and conflicting evidence rather than forcing crisp or purely probabilistic judgments. Neutrosophic sets and neutrosophic fuzzy extensions have been widely applied to multi-criteria decision-making problems in engineering, sustainability and management, where evaluators must integrate heterogeneous criteria under uncertainty (Nafei et al., 2023).

Recent work has started to use neutrosophic-based frameworks in domains close to the built environment. For example, neutrosophic multi-criteria decision-making has been used to evaluate sustainable alternatives for the structural design of single-family homes and green construction systems, explicitly modelling expert uncertainty and disagreement about environmental, social and economic indicators (Sánchez-Garrido et al., 2021). Neutrosophic decision models have also been applied to the selection and prioritisation of renewable energy strategies—such as solar photovoltaic farms, sustainable energy mixes or hydrogen production technologies—under conflicting criteria of cost, reliability, security and carbon impact (Abdel-Basset et al., 2021). In parallel, a probabilistic simplified neutrosophic TOPSIS framework has been proposed for evaluating the quality of environmental art design in green building contexts, capturing partial agreement and indeterminacy in multi-expert assessments of aesthetic and sustainability attributes (Wang et al., 2024). Beyond environmental and energy applications, a recent original research article has shown that neutrosophic explainable AI can be used to model uncertainty and ambiguity in immersive stereotactic neurosurgical simulation, further illustrating the suitability of neutrosophic models for complex, high-stakes evaluative contexts (Hechavarria-Hernandez, 2026). Together, these studies indicate that neutrosophic models are particularly well suited to settings where evaluations are subjective, plural and context-dependent—conditions that closely resemble architectural appraisal when ethical and symbolic dimensions such as fairness, identity and sustainability are at stake.

However, current neutrosophic applications typically operate at the level of abstract criteria and alternatives (e.g., ranking design options), rather than being tightly integrated with VR-based experiential data or psychophysiological measures. The potential of neutrosophic logic to model users' ambiguous and sometimes contradictory responses to symbolic aspects of virtual architectural spaces remains largely unexplored.

A first application of neutrosophic multiperspectivism to architecture was presented in the Technarrative Model (NTM), which used triads ⟨T, I, F⟩ and OWA aggregation to reconcile divergent symbolic–emotional evaluations of a public building by community members, preservationists and other stakeholders. NTM showed that neutrosophic tools are able to represent polarization and ambiguity in architectural appraisal without forcing consensus, and that they can reveal zones of high symbolic tension that may guide future design or policy interventions. However, NTM operated on a static, real-world case and relied solely on stakeholder judgments. The Neutrosophic Technarrative Architecture (NTA) proposed here extends this logic into dynamic virtual environments, combining neutrosophic evaluation with VR-based experimentation, psychophysiological sensing and AI modelling.

2.6 Summary and identified gaps

The literature reviewed above points to several converging trends:

1. VR, neuroarchitecture and biometrics provide powerful tools to study human responses to architectural environments, but existing protocols are fragmented and often focus on low-level features and generic affective states (Taherysayah et al., 2024).
2. VR biofeedback systems demonstrate the feasibility of integrating physiological signals into adaptive environments, yet are rarely grounded in explicit models of architectural meaning or ethically loaded constructs such as justice, identity or hope (Lüddecke and Felnhofer, 2021).
3. Architectural theory and design semiotics offer nuanced accounts of symbolic and narrative dimensions of space, but these have not been systematically operationalised in VR experiments or linked to multimodal user data (Sūdžiūtė, 2023).
4. Neutrosophic logic provides a rigorous mathematical framework for representing indeterminacy and inconsistency in multi-criteria evaluation, including in design-related contexts, yet it has not been integrated with VR user experience research or neuroarchitectural methods (Nafei et al., 2023).

These gaps motivate the development of an integrative, theory-driven framework that (a) encodes symbolic–narrative constructs of architectural space in a formal, manipulable way, (b) leverages VR, biofeedback and interaction logs to capture multimodal user responses, and (c) uses neutrosophic representation to model the

ambiguity and partiality inherent in symbolic–emotional evaluations. The Neutrosophic Technarrative Architecture (NTA) proposed in this article is intended to address this need and to provide a testable conceptual foundation for future empirical research.

3 The neutrosophic technarrative architecture (NTA)

3.1 Conceptual overview

The Neutrosophic Technarrative Architecture (NTA) is proposed as a multi-layer conceptual framework for analysing how users experience symbolic–emotional aspects of virtual architectural spaces. Rather than treating virtual environments, physiological signals and self-reported emotions as separate domains, NTA links them through a single, theory-driven pipeline grounded in:

1. A symbolic–narrative model of architecture, the Neutrosophic Technarrative Model (NTM);
2. Immersive VR scenarios that instantiate specific combinations of symbolic nodes;
3. Biofeedback and interaction data capturing users' embodied responses;
4. A data fusion layer that organises multi-modal information; and
5. Artificial intelligence (AI) models that learn relationships between symbolic design variables and user responses, using neutrosophic representation to handle ambiguity and indeterminacy.

Conceptually, NTA assumes that:

- Architectural spaces carry symbolic narratives (e.g., justice, identity, hope) that can be partially formalised and encoded into virtual environments.
- Users' experiences of these narratives are multi-layered: cognitive, emotional, bodily and behavioural.
- Their evaluations are often ambiguous or internally conflicting (a space can feel welcoming and oppressive at the same time), which motivates the use of neutrosophic logic (T–I–F) rather than only single-valued or purely probabilistic scales.
- VR, biofeedback and AI provide a technical substrate where these links can be systematically explored and eventually used to inform design practice.

NTA is not a single algorithm or software, but a research architecture: a structured way of connecting symbolic design, experimental VR protocols and computational analysis in a manner that is replicable, extensible and testable in empirical studies.

3.2 NTM nodes and symbolic encoding of virtual spaces

At the core of NTA lies the Neutrosophic Technarrative Model (NTM), which conceptualises architectural experience in terms of a set of symbolic nodes. In the present formulation, we focus on five primary nodes that are particularly relevant for ethical, social and environmental dimensions of space:

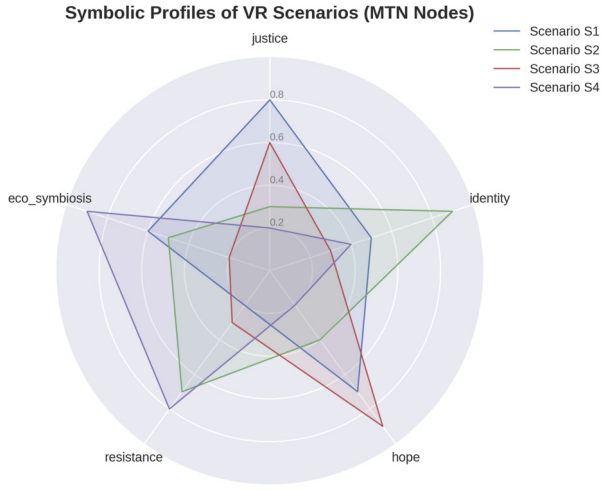

FIGURE 1
Symbolic profiles of virtual reality scenarios according to NTM nodes. Radar chart showing the scenario-level configuration of the five NTM symbolic dimensions (Justice, Identity, Hope, Resistance and Eco-Symbiosis) for four illustrative VR scenarios (S1–S4). These scenario profiles define the symbolic "intentionality" of each environment and constitute the input layer for NTA, guiding both the design of visual scripts in VR and the interpretation of subsequent user responses. The symbolic node determination process follows the reproducible coding protocol described in Supplementary Appendix SA and illustrated in Supplementary Table SA1.

- Justice – spatial expressions of fairness, inclusion, accessibility, visibility of power relations, and perceived equity in how space allocates resources and opportunities.
- Identity – articulation of cultural, territorial or personal identity, including references to memory, belonging, roots and recognisable symbols of community.
- Hope – orientation towards the future, openness to change, perceived possibility of growth, regeneration or improvement embedded in spatial narratives.
- Resistance – capacity of space to express dissent, protect from oppression, or symbolically resist harmful conditions (e.g., authoritarian control, environmental degradation).
- Eco-symbiosis – degree to which space symbolically and materially integrates natural elements, ecological cycles and non-human life as co-present actors rather than mere background.

This node set builds directly on our previous Technarrative Model (NTM) for the symbolic–emotional evaluation of architectural space, where these dimensions were identified and formalised as core narrative constructs in participatory assessments of built environments (Hechavarría-Hernández et al., 2025). The methodological protocol used to derive the NTM symbolic nodes is described in Supplementary Appendix SA to ensure transparency and reproducibility of the symbolic abstraction process. The derivation of these symbolic nodes follows a structured coding

TABLE 1 Traceability of NTM symbolic nodes and their conceptual antecedents.

NTM node	Antecedents in NTM/Literature	Conceptual justification
Justice	Community benefit, gentrification	Ethical spatial equity
Identity	Neighborhood identity, continuity	Sense of place and belonging
Hope	Positive projection, safety	Future-oriented environment
Resistance	Heritage conflict, boundaries	Defensible and symbolic space
Eco-symbiosis	Biophilic integration	Human-environment harmony

protocol detailed in Supplementary Appendix SA, including traceability examples presented in Supplementary Table SA1. The reproducible symbolic abstraction workflow is further illustrated in Supplementary Appendix SA (Supplementary Figure SA1). The relationship between the Neutrosophic Technarrative Model (NTM) and the proposed Neutrosophic Technarrative Architecture (NTA) is clarified in Supplementary Appendix SA (Supplementary Table SA2), where their conceptual roles and levels of novelty are explicitly compared.

In the context of NTA, each virtual scenario is defined by a symbolic profile across the NTM nodes. Figure 1 presents an illustrative example in which four VR scenarios (S1–S4) differ systematically in their levels of Justice, Identity, Hope, Resistance and Eco-Symbiosis. These profiles specify the intended symbolic configuration of each environment and serve as the starting point for NTA: they inform the design of the scene (e.g., spatial layouts, materials, access patterns) and provide the reference against which users' neutrosophic evaluations and biofeedback responses are later interpreted.

3.2.1 Derivation and delimitation of the NTM nodes

The five symbolic nodes utilized in NTA (Justice, Identity, Hope, Resistance, and Eco-symbiosis) are derived from the methodological framework established in our previous work on the Neutrosophic Technarrative Model (NTM). While NTM focused on eliciting symbolic-emotional attributes through multiperspective architectural evaluation, NTA synthesizes these into higher-order categories suitable for VR implementation. Justice and Identity are grounded in NTM's precedents regarding neighborhood appropriation and spatial equity. Resistance is derived from conflict-based heritage assessments, while Hope is introduced as a future-oriented projection. Eco-symbiosis represents an extension of the framework, integrating sustainability and biophilic design principles. This synthesis is supported by current literature in spatial ethics and place identity, as summarized in Table 1.

3.2.2 From abstract nodes to design features

For each NTM node, NTA requires a mapping to concrete design features that can be implemented in virtual scenarios. For example:

- Justice may be associated with:
  - visibility and transparency (e.g., open vs. opaque boundaries),
  - accessibility (ramps, equitable circulation paths),
  - spatial symmetry or balance in allocation of key spaces.
- Identity may be expressed through:
  - vernacular materials and textures,
  - references to local iconography,
  - spatial sequences that evoke familiar cultural rituals.
- Hope may be linked to:
  - verticality and upward trajectories,
  - abundant natural light,
  - vistas towards open or "beyond" spaces.
- Resistance may be encoded via:
  - protective thresholds and refuges,
  - counter-monumental gestures,
  - asymmetry or fragmentation that challenges dominant orders.
- Eco-symbiosis may involve:
  - integration of vegetation and water,
  - permeability to light, air and natural cycles,
  - visible ecological infrastructures (e.g., green roofs, water reuse elements).

These mappings are context-dependent and may vary culturally, but NTA requires that they be explicitly documented as part of the scenario design: each virtual environment is assigned a symbolic profile specifying which nodes are targeted and at what intended intensity (e.g., high justice, medium hope, low resistance).

3.2.3 Symbolic metadata for VR scenarios

Practically, each virtual scenario is accompanied by a metadata structure that includes:

- a list of active NTM nodes (e.g., {justice, identity, eco-symbiosis}),
- qualitative descriptions of how each node is expressed,
- quantitative or ordinal parameters (e.g., low/medium/high intensity levels),
- links to specific spatial regions or features (e.g., justice_zone_1 = central courtyard, identity_zone_2 = entrance sequence).

This symbolic metadata forms the input layer of NTA and allows subsequent analyses to connect user responses not just to generic "Scenario A vs. B", but to specific symbolic configurations embedded in the virtual space. From a VR development perspective, these symbolic nodes and their associated parameters become concrete design variables: for example, "justice" can be implemented by scripting equal access to key areas and balanced visibility in the scene, "identity" by activating specific material

libraries, iconographic assets or soundscapes per cultural profile, and "hope" by configuring light, vistas and vertical movement paths through the environment.

3.3 System layers: from NTM encoding to AI models

NTA organises the research process into a series of interconnected layers. Conceptually, the pipeline can be summarised as:

$$\text{NTM encoding} \rightarrow \text{VR scenarios} \rightarrow \text{biofeedback and interaction capture} \rightarrow \text{data fusion} \rightarrow \text{AI and neutrosophic analysis}$$

Each layer has a distinct function:

3.3.1 Layer 1 – NTM encoding

- Input: architectural and experiential questions (e.g., "How does a just learning environment feel?").
- Process:
  - select relevant NTM nodes,
  - define design features and spatial strategies that express each node,
  - assign intended intensities and regions.
- Output: a symbolic specification for each scenario (metadata).

3.3.2 Layer 2 – VR scenario implementation

- Input: symbolic specification + geometric/functional requirements.
- Process:
  - creation of 3D models (parametric or manual),
  - integration into a VR engine (Unity, Unreal, WebXR),
  - implementation of navigation and interaction mechanics.
- Output: immersive VR environments that instantiate the symbolic profiles defined in Layer 1, with pre-defined zones of interest linked to NTM nodes.

3.3.3 Layer 3 – Biofeedback and interaction capture

- Input: VR scenarios and user sessions.
- Process:
  - recording of psychophysiological signals (EEG, GSR, HRV) during exploration,
  - logging of behavioural data (paths, time in zones, gaze, interactions),
  - placement of synchronisation markers when users enter or exit symbolic zones.
- Output: raw multi-modal time-series and event logs per participant × scenario.

3.3.4 Layer 4 – data fusion and feature construction

- Input: raw signals and logs + symbolic metadata.

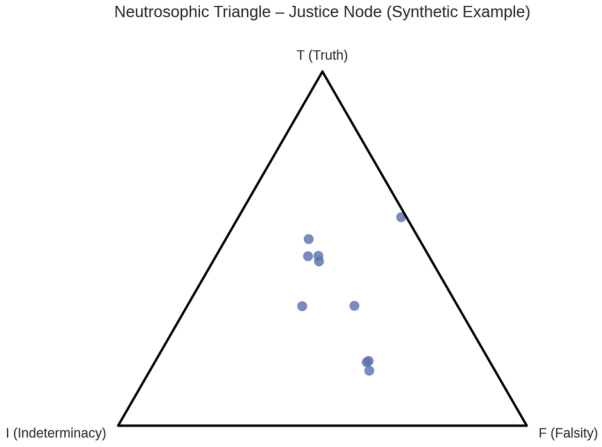

FIGURE 2
Neutrosophic triangle representation for synthetic Justice evaluations. Example of how individual evaluations for the Justice node can be mapped into the T–I–F simplex, using a barycentric projection of Truth (T), Indeterminacy (I) and Falsity (F) onto a triangular 2D space. The plot is generated from fully synthetic data and is provided as an implementation-oriented visual aid for researchers interested in reproducing or extending the NTA mapping.

- Process:
  - pre-processing of physiological signals (filtering, artefact removal, feature extraction),
  - segmentation by scenario and symbolic region,
  - aggregation of behavioural metrics (e.g., dwell time, path complexity),
  - integration of self-reported symbolic–emotional evaluations (NTM questionnaires).
- Output: feature matrices where each row corresponds to participant × scenario (or participant × region) and columns include:
  - symbolic design variables (NTM intensities),
  - physiological features,
  - behavioural features,
  - self-report scores and their neutrosophic decomposition.

3.3.5 Layer 5 – AI models and interpretive analytics

- Input: fused feature matrices.
- Process:
  - statistical analyses (e.g., correlations, regression, mixed models) to test specific hypotheses,
  - machine learning models (e.g., random forests, gradient boosting, neural networks) to:
    - predict symbolic–emotional evaluations from design + physiology + behaviour,
    - identify clusters of users or scenario types with similar response profiles,
  - exploration of explainable AI (XAI) tools to attribute model outputs to specific symbolic and spatial features.
- Output:
  - quantitative evidence for or against the hypothesised relationships in NTA,

- interpretable patterns connecting symbolic encoding with embodied user experience.

In this article, these layers are described conceptually and illustrated as a methodological blueprint. Future empirical work can instantiate them with specific tools, sensors and datasets according to project constraints.

3.4 Neutrosophic representation (T–I–F) of evaluations

A distinctive feature of NTA is its use of neutrosophic representation to model users' evaluations of symbolic–emotional qualities. Instead of assuming that each user's judgment can be captured by a single scalar (e.g., a one to seven Likert score), NTA adopts the neutrosophic triad:

- T (truth): degree to which the user supports a given statement (e.g., "this space feels just").
- I (indeterminacy): degree of uncertainty, ambiguity or mixed feelings (e.g., the user is unsure, experiences conflicting cues, or finds the judgment difficult).
- F (falsity): degree to which the user rejects the statement (e.g., "this space does not feel just").

For readers interested in the geometric interpretation of neutrosophic triads, Figure 2 provides a simple example of how Justice-related evaluations can be projected onto a T–I–F simplex, highlighting clusters of agreement, indeterminacy and disagreement within the same symbolic node.

3.4.1 From questionnaire responses to T–I–F

In practice, NTM-based self-report instruments can be designed so that:

- Some items reflect affirmation of a symbolic quality (e.g., "The space feels inclusive and fair"),
- Others reflect its negation (e.g., "The space privileges some users over others"),
- And additional items probe ambivalence or uncertainty (e.g., "I have mixed feelings about how fair this space is").

From these patterns, neutrosophic components can be derived for each node and scenario. For example:

- High agreement with positive items and low agreement with negative items → high T, low F, low I;
- Moderate agreement with both positive and negative items → moderate T, moderate F, high I;
- Low agreement with all items (including positive, negative and mixed) → lower T and F, potentially higher I (uncertainty or disengagement).

Other mappings are also possible, for instance using neutrosophic fuzzy membership functions or transforming standard Likert scores into T–I–F triplets according to pre-defined rules.

3.4.2 Advantages for symbolic–emotional evaluation

The neutrosophic representation offers several advantages in the context of symbolic–emotional assessment:

1. Capturing ambiguity: users often experience spaces as simultaneously welcoming and threatening, or fair and unfair in different respects. A single scalar cannot represent such internal contradictions, whereas T–I–F explicitly acknowledges them.
2. Differentiating doubt from neutrality: low scores in classical scales can mean disagreement, indifference or uncertainty. Neutrosophic I allows researchers to distinguish "I do not know" from "I clearly disagree".
3. Enhancing model interpretability: when AI models are trained on T–I–F components, designers can ask not only "which features increase perceived justice (T)" but also "which features reduce indeterminacy (I)" or "which features trigger strong rejection (F)".
4. Aligning with decision-making under uncertainty: architectural design often involves negotiating conflicting criteria and stakeholder perspectives. Neutrosophic measures can be directly reused in multi-criteria decision-making frameworks, bridging experiential evaluation and design choice.

In our previous application of the Technarrative Model (NTM) to a heritage building, the indeterminacy component (I) proved particularly informative to distinguish genuine disagreement from uncertainty among stakeholder groups, revealing zones of symbolic tension that would have been obscured by single-valued ratings (Hechavarría-Hernández et al., 2025). In NTA we extend this rationale to VR user experience, where mixed or undecided responses to symbolic qualities are frequent and should not be collapsed into a single score.

Within NTA, neutrosophic evaluations are treated as both:

- Dependent variables (e.g., predicting T–I–F for justice based on VR + biofeedback features), and
- Diagnostic indicators that help interpret how symbolic narratives are received by different users and under different conditions.

The definition of the neutrosophic representation naturally raises the question of how NTA relates to existing affective, neuroarchitectural, and VR evaluation frameworks. The following subsections establish the theoretical foundations that position NTA as a distinct research framework and clarify its conceptual and methodological contribution to architectural evaluation science.

3.5 Positioning of NTA within affective and neuroarchitectural frameworks

The Neutrosophic Technarrative Architecture (NTA) extends existing architectural evaluation paradigms by integrating symbolic, emotional, and uncertainty-aware dimensions into a unified, computationally tractable, and empirically testable framework.

TABLE 2 Comparative positioning of NTA.

Framework	Emotional evaluation	Symbolic evaluation	Uncertainty modeling	VR integration	AI integration
Kansei engineering	Yes	No	Limited	Partial	Rare
Affective computing	Yes	No	No	Limited	Partial
Neuroarchitecture	Yes	No	No	Yes	Limited
VR emotional studies	Yes	No	No	Yes	Yes
NTA	Yes	Yes	Yes (neutrosophic)	Yes	Yes

Classical Kansei Engineering (Nagamachi, 2010) focuses primarily on emotional perception mapping, whereas NTA incorporates axiological symbolic constructs such as justice, identity, and resistance as explicit evaluative dimensions. Similarly, affective computing approaches (Calvo et al., 2014) concentrate on emotion detection and classification but do not formally integrate symbolic meaning structures within spatial experience. Neuroarchitectural research (Brass et al., 2017) typically focuses on physiological responses to spatial stimuli but rarely incorporates structured symbolic interpretation layers capable of representing cognitive ambiguity. NTA introduces a fundamental theoretical extension through neutrosophic representation (Smarandache, 2020), enabling explicit modeling of:

- positive interpretation
- negative interpretation
- cognitive indeterminacy

This allows architectural perception to be treated as a multidimensional interpretative process rather than a single emotional outcome. To clarify these distinctions, Table 2 positions NTA relative to existing approaches.

The symbolic nodes integrated into NTA are derived through a structured qualitative abstraction protocol described in Supplementary Appendix SA.

3.6 Mathematical and cognitive advantages of neutrosophic modeling

Traditional Likert scales assume emotional responses can be represented as single scalar values. However, architectural perception frequently involves simultaneous and potentially conflicting interpretations emerging from symbolic meaning, spatial configuration, and individual experience. For example, a spatial configuration characterized by transparency may simultaneously evoke:

- Openness → positive interpretation
- Exposure → negative interpretation

Such dual interpretations reflect emotional ambivalence and cognitive dissonance commonly observed in environmental perception research. Scalar representations such as Likert scales typically compress these multidimensional responses into a single aggregated value, potentially obscuring internal perceptual conflicts. Probability models represent uncertainty as stochastic variability rather than cognitive indeterminacy, while fuzzy logic effectively models vagueness but does not explicitly separate positive, negative, and indeterminate perceptual states.

Neutrosophic logic (Smarandache, 2020) introduces a triadic representation of perception:

$$P = (T, I, F)$$

where:

- T represents degree of positive interpretation.
- I represents degree of indeterminacy.
- F represents degree of negative interpretation.

This representation allows simultaneous modeling of:

- Emotional ambivalence
- Symbolic conflict
- Cognitive indeterminacy

Which are common in architectural experience.

From a cognitive perspective, this triadic structure aligns with multi-state emotional appraisal theories suggesting that environmental perception may contain unresolved interpretative states rather than binary evaluations. Mathematically, neutrosophic representation preserves informational structure by avoiding scalar collapse of perception states and enabling richer knowledge representation of architectural experience.

This provides the theoretical basis for integrating:

- Symbolic encoding
- Physiological response
- Subjective evaluation
- AI-supported interpretation

Within the NTA framework.

The symbolic perception states used in this representation originate from a structured symbolic coding process described in Supplementary Appendix SA and illustrated through traceability examples in Supplementary Table SA1.

3.7 Illustrative comparative scenario

To illustrate the theoretical advantage of neutrosophic modeling, consider a virtual reality architectural environment characterized by high transparency and visual openness, which may simultaneously evoke perceptions of freedom and

vulnerability. Within such environments, participants may report concurrent interpretations such as:

- Perceived openness → positive symbolic/emotional response.
- Perceived exposure → negative symbolic/emotional response.
- Perceived ambiguity → uncertain cognitive interpretation.

Traditional Likert-based representations typically compress these multidimensional perceptions into a single scalar value through aggregation, potentially obscuring conflicting interpretations inherent to architectural experience.

For example:

Likert representation:

Emotional evaluation = 3.5/5.

This scalar representation does not preserve the coexistence of positive, negative, and uncertain interpretations.

By contrast, neutrosophic representation allows simultaneous modeling:

- T (positive perception) = 0.6
- I (indeterminacy) = 0.3
- F (negative perception) = 0.4

This representation preserves the structural complexity of architectural perception by explicitly capturing emotional ambivalence and cognitive uncertainty. Within the NTA framework, such representations can be directly linked to:

- Symbolic encoding of spatial elements
- VR exposure scenarios
- Physiological measurements (EEG, HRV, GSR)
- Symbolic-emotional questionnaires
- AI-supported analysis pipelines

This integrative capacity illustrates why NTA should be considered not merely an extension of affective architectural evaluation, but a new theoretical category integrating symbolic cognition, multimodal measurement, and uncertainty representation. From an epistemological perspective, neutrosophic representation enables architectural perception to be treated as a multi-state cognitive phenomenon rather than a single emotional outcome, allowing richer knowledge representation of spatial experience. In summary, the Neutrosophic Technarrative Architecture provides an integrated conceptual lens through which symbolic encoding, immersive experience, embodied response, and ambiguous evaluation can be jointly studied. The theoretical justification of symbolic–design mappings is provided in Section 3.8.

3.8 Literature-grounded symbolic–design mappings

The symbolic–design mappings proposed in the Neutrosophic Technarrative Architecture framework are not arbitrary design associations but literature-informed hypotheses derived from architectural theory, environmental psychology, and spatial cognition research. Rather than presenting deterministic relationships, NTA proposes testable symbolic–design hypotheses grounded in established theoretical traditions including:

- Environmental psychology
- Neuroarchitecture
- Space syntax theory
- Biophilic design
- Place identity theory
- Prospect-refuge theory

These traditions provide theoretical justification for how spatial characteristics influence emotional and cognitive perception. Table 3 summarizes the theoretical grounding of the proposed mappings.

The mappings proposed in NTA should therefore be interpreted as theory-informed architectural hypotheses rather than deterministic design rules. Their purpose is to provide a reproducible experimental structure allowing empirical validation through VR exposure and biometric measurement. This approach aligns NTA with hypothesis-driven research frameworks commonly used in neuroarchitecture and environmental cognition studies. To ensure reproducibility, these mappings are defined as explicit experimental assumptions rather than designer intuition. NTA therefore transforms symbolic architectural interpretation into a structured Scientific Decision Architecture process. The following sections translate this conceptual structure into concrete research aims, hypotheses, and methodological guidelines for future empirical validation.

4 Research aims, hypothesis and questions

The Neutrosophic Technarrative Architecture (NTA) is proposed as a theory-driven framework that can be empirically tested in future studies. This section specifies the overarching aim, the general hypothesis and a set of research questions that operationalise the conceptual claims made in Sections 2, 3.

4.1 Visual-semantic mappings as design hypotheses

To translate conceptual symbolic nodes into tangible spatial configurations, we established a set of visual-semantic mappings. We explicitly propose that these associations (e.g., transparency for Justice, verticality for Hope) function as design hypotheses rather than universal architectural rules. The proposed mappings are informed by established research in environmental psychology, neuroarchitecture, place identity theory, and spatial cognition, which demonstrate systematic relationships between spatial characteristics and emotional perception. These mappings should therefore be interpreted as literature-informed experimental assumptions rather than intuitive associations.

We recognize that such mappings are culturally mediated and context-dependent, necessitating empirical validation across diverse user groups. To ensure transparency in our symbolic inference process, we present a Symbolic Inference Chain (Figure 3), which articulates the logical progression from high-level abstract nodes to

TABLE 3 Literature-grounded symbolic–design mappings in NTA.

NTM node	Design feature	Theoretical basis	Supporting research tradition
Justice	Transparency, visibility, spatial accessibility	Perceived fairness correlates with visibility and equal spatial access	Space syntax, procedural justice environments
Hope	Verticality, open views, natural light	Upward visual fields associated with optimism and future orientation	Prospect-refuge theory, environmental psychology
Identity	Local materials, cultural symbols	Spatial familiarity reinforces belonging	Place identity theory, phenomenology of architecture
Resistance	Spatial control, territorial markers	Perceived control increases psychological empowerment	Defensible space theory, territoriality research
Sustainability	Natural integration, vegetation	Nature exposure improves cognitive restoration	Biophilic design, restorative environment theory

FIGURE 3
Symbolic inference chain: from conceptual nodes to VR design parameters.

specific, quantifiable VR design parameters. This chain serves as the framework for our hypothesis-driven experimental design, facilitating the controlled manipulation of architectural meaning within virtual environments.

4.2 General research aim

The general aim of this work is:

To develop and theoretically ground an integrated framework, based on the Neutrosophic Technarrative Model (NTM), virtual reality (VR), biofeedback and artificial intelligence (AI), capable of evaluating the symbolic–emotional impact of virtual architectural spaces on users.

This aim has two complementary dimensions:

1. Conceptual – to articulate how symbolic–narrative constructs (e.g., justice, identity, hope, resistance, eco-symbiosis) can be encoded in virtual environments and linked to multi-modal user responses.
2. Methodological – to provide a testable blueprint for future empirical research, specifying scenarios, measurements and analytical strategies.

4.3 General hypothesis

From this aim, the following general hypothesis is proposed:

H1 (General Hypothesis).

An integrated framework based on the Neutrosophic Technarrative Model (NTM), implemented in immersive VR and instrumented with biofeedback (EEG, GSR, HRV) and AI algorithms, will predict users' symbolic–emotional evaluations of virtual architectural spaces more accurately and coherently than approaches relying solely on physical–functional metrics or self-report measures.

In this hypothesis:

- The symbolic configuration of the virtual space, as encoded by NTM nodes and intensities, constitutes the main independent variable.
- Physiological and behavioural features (biofeedback and VR interaction logs) act as mediating or explanatory variables.
- Users' symbolic–emotional evaluations, including their neutrosophic decomposition into truth (T), indeterminacy (I) and falsity (F), are the primary dependent variables.

Although this paper does not test H1 empirically, the hypothesis is formulated so that it can be evaluated in future experimental studies using the methodological blueprint presented in Section 5.

4.4 Research questions

To make the general hypothesis operational and to guide empirical work using NTA, four specific research questions are proposed.

RQ1 – Symbolic design and self-reported evaluations (VR + NTM)

RQ1. To what extent are virtual spatial configurations designed and encoded through the Neutrosophic Technarrative Model (NTM) associated with users' self-reported symbolic–emotional evaluations (e.g., justice, identity, hope, resistance, eco-symbiosis) in immersive VR environments?

RQ1 focuses on the relationship between:

- Symbolic design variables (which NTM nodes are targeted and at what intensity), and
- Subjective evaluations captured by NTM-based questionnaires.

It addresses whether changes in symbolic encoding produce systematic changes in perceived justice, identity, hope and related constructs.

RQ2 – Symbolic design and physiological responses (VR + biofeedback)

RQ2. How do neurophysiological patterns (EEG, GSR, HRV) recorded while users navigate virtual spaces with different symbolic configurations relate to variations in perceived emotional impact?

Here, the emphasis is on:

- Whether specific combinations of NTM nodes and design features elicit distinct psychophysiological signatures (e.g., patterns of arousal, regulation, cognitive load), and
- How these signatures align with reported emotional states (e.g., comfort, tension, engagement) in symbolic contexts.

RQ3 – Predictive capacity of integrated AI models (NTM + VR + biofeedback)

RQ3. To what extent can AI models that integrate symbolic variables (NTM nodes), VR interaction data (navigation, gaze, time in symbolic zones) and biofeedback signals predict users' symbolic–emotional evaluations more accurately than models based solely on self-report?

RQ3 explicitly compares:

- Baseline models that rely only on questionnaire data, with
- Integrated models that combine symbolic design descriptors, physiological features and behavioural metrics.

The question targets the added value of multimodal integration for understanding and predicting symbolic–emotional experience.

RQ4 – Added value of neutrosophic representation (T–I–F)

RQ4. In what ways does the neutrosophic representation of evaluations (truth, indeterminacy and falsity; T–I–F) better capture the ambiguity and complexity of symbolic–emotional experience in virtual architectural spaces compared to traditional linear or purely probabilistic scales?

This question addresses whether:

- Neutrosophic scores (T–I–F) provide richer information than single-valued ratings,
- They improve model fit and interpretability when used in statistical and AI analyses, and
- They help differentiate between disagreement, uncertainty and neutrality in users' judgments about symbolic qualities of space.

These questions are also informed by patterns of ambiguity and polarization observed in our previous NTM study, where neutrosophic triads revealed complex constellations of agreement, disagreement and uncertainty in symbolic evaluations of real architectural spaces (Hechavarría-Hernández et al., 2025). Together, H1 and RQ1–RQ4 define a coherent research programme: NTA is introduced here as a conceptual and methodological framework, and these questions specify how future empirical studies can test, refine and extend the architecture in concrete VR–based experiments.

5 Methodological blueprint: testability of the framework

Although this article is conceptual and does not report empirical data, the Neutrosophic Technarrative Architecture (NTA) is explicitly designed to be testable. This section outlines a methodological blueprint for a future empirical study that could operationalise the framework and address the research questions formulated in Section 4.

The proposed design is within-subjects, with each participant exposed to multiple symbolically encoded VR scenarios, while multimodal data (self-report, biofeedback and interaction logs) are collected.

5.1 Participants and sampling

A first empirical implementation of NTA can employ a convenience sample of approximately 30–40 participants, a range consistent with experimental studies combining VR exposure and biometric measurements (EEG, GSR, HRV), where typical sample sizes range between 20 and 50 participants due to the intensive nature of immersive experimental protocols and multimodal data collection requirements. Given that this work proposes NTA as a hypothesis-driven research framework, the proposed sample size should be interpreted as appropriate for an exploratory pilot validation study focused on feasibility testing and effect detection rather than population-level statistical generalization.

Participants may be drawn from:

- architecture, interior design and related programmes, and/or
- early-career professionals interested in spatial experience and VR

Architecture-related participants are proposed as an initial study population because their spatial literacy and design training may allow more consistent identification and interpretation of symbolic architectural cues. This follows common practices in early-stage neuroarchitecture and environmental cognition studies where domain-aware participants are used to test theoretical frameworks before broader validation. Nevertheless, it is acknowledged that this population may interpret symbolic spatial features differently from the general population. Therefore, future empirical implementations of NTA should include more diverse participant groups to evaluate the generalizability of the framework. Inclusion criteria would typically include:

- Age 18+ with normal or corrected-to-normal vision.
- No self-reported history of severe neurological disorders or photosensitive epilepsy.
- Basic familiarity with 3D environments (e.g., video games or VR) desirable but not mandatory.

Participants would provide written informed consent, and the study protocol would be approved by an institutional ethics committee. Sample sizes in immersive VR studies frequently prioritize experimental control and data quality over statistical representativeness, particularly in early-stage framework validation.

TABLE 4 Operational VR design specifications and implementation parameters.

Node	Operational definition in VR	Design parameters
Justice	High transparency and equitable access	Global illumination >800 lux; occlusion <10%
Hope	Verticality and open horizons	Ceiling height >3.5 m; vertical visual axis
Identity	Culturally anchored visual cues	Localized textures; iconographic landmarks
Resistance	Thresholds and spatial fragmentation	Irregular circulation; clear defensive boundaries
Eco-symbiosis	Biophilic integration	Vegetation density >20%; natural light-air permeability

TABLE 5 Relative importance of scenario-level symbolic variables and biofeedback features in predicting synthetic symbolic engagement (Random Forest model).

Feature	Relative importance	Category
Resistance	0.00781	Symbolic
Justice	0.01313	Symbolic
Eco-symbiosis	0.02540	Symbolic
Hope	0.04969	Symbolic
Identity	0.16613	Symbolic
GSR peaks	0.17466	Biometric
HRV mean	0.22798	Biometric
EEG Alpha	0.33517	Biometric

5.2 Operational VR design specifications

To ensure the reproducibility of our experimental VR environments, we have established a set of operational parameters that bridge symbolic concepts with technical implementation. We define these specifications as operational hypotheses, linking symbolic intensity (e.g., high vs. low Justice) to concrete technical VR settings. These parameters provide a replicable framework for constructing virtual scenarios, allowing other researchers to reconstruct and test the symbolic profiles proposed in the NTA framework. The operational specifications and implementation parameters are summarized in Table 4.

The operational parameters detailed in Table 4 provide the static technical requirements for our VR environments. To ensure a systematic rather than fragmented approach, Figure 4 illustrates the underlying data pipeline. This pipeline outlines the proposed computational architecture for processing raw VR inputs and biometric data, designed to integrate neuro-computational (CNN-LSTM) layers for affective state extraction, which are intended to be subsequently mapped onto our symbolic nodes (Justice, Identity, Hope, Resistance, Eco-symbiosis) through neutrosophic inference. This integrated architecture represents the technical roadmap for the NTA framework, ensuring that experimental outcomes move beyond merely technical validations toward structured, axiologically-grounded assessments of architectural meaning.

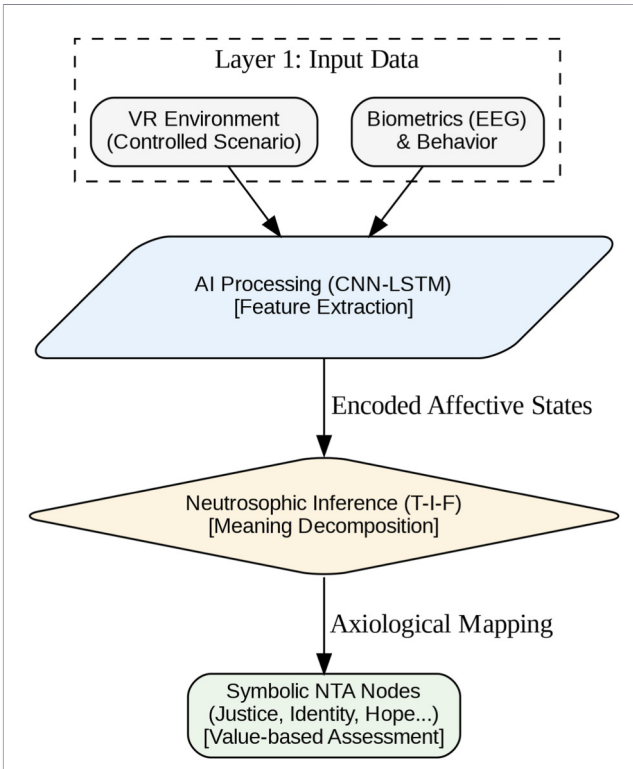
Layer 1: Input Data
VR Environment (Controlled Scenario)
Biometrics (EEG) & Behavior
AI Processing (CNN-LSTM) [Feature Extraction]
Encoded Affective States
Neutrosophic Inference (T-I-F) [Meaning Decomposition]
Axiological Mapping
Symbolic NTA Nodes (Justice, Identity, Hope...) [Value-based Assessment]

FIGURE 4
Integrated NTA data pipeline: From multi-modal biometric inputs to symbolic-axiological assessment.

5.3 VR scenarios and symbolic conditions

A set of 3–6 virtual architectural scenarios would be created to instantiate different NTM-based symbolic profiles. These scenarios are designed as controlled experimental environments where symbolic variables can be systematically manipulated while maintaining comparable spatial complexity. Example symbolic configurations include:

- Scenario A: high Justice, medium Identity, low Resistance, medium Hope, low Eco-symbiosis.
- Scenario B: medium Justice, high Identity, low Resistance, high Hope, medium Eco-symbiosis.
- Scenario C: low Justice, low Identity, high Resistance, low Hope, medium Eco-symbiosis.

These examples illustrate how NTM node intensities can be combined to create differentiated symbolic environments.

Each scenario would be:

- Modelled in 3D (e.g., parametric tools or Blender) while maintaining control over baseline spatial parameters (area, ceiling height, circulation complexity).
- Implemented in a VR engine (e.g., Unity, Unreal Engine, WebXR) allowing free navigation and standardized interaction conditions.
- Annotated with symbolic metadata specifying:
  - Active NTM nodes and intended intensity levels.
  - Key spatial zones associated with each symbolic node (e.g., justice_zone_1, identity_zone_2).
  - Symbolic design features associated with each node.

To improve experimental control, baseline architectural variables (scale, lighting conditions, navigation time, and interaction affordances) would be maintained as constant as possible across scenarios, while symbolic design variables constitute the primary manipulated factors. The order of scenario presentation would be counterbalanced across participants to mitigate order effects and learning bias.

5.3.1 Scenario construction rationale

The scenario profiles proposed in this work are not intended to represent an exhaustive factorial combination of all NTM nodes, but rather a set of controlled symbolic contrasts designed to demonstrate how symbolic configurations can be experimentally manipulated within the NTA framework.

Scenario construction follows three methodological principles:

1. Symbolic contrast principle. Scenarios are constructed to maximize perceptual differentiation between symbolic conditions (for example, high Justice vs. low Hope) to facilitate detection of symbolic–emotional effects in exploratory validation studies.

This approach follows experimental design practices where controlled contrasts improve interpretability of behavioral and physiological responses.

2. Experimental feasibility principle. A complete factorial combination of NTM nodes and intensity levels would generate a large number of scenarios. Such designs may increase:
   - Participant fatigue
   - VR adaptation effects
   - Experimental noise

Therefore, NTA proposes a reduced set of representative symbolic configurations suitable for pilot experimental validation.

3. Framework extensibility principle. The proposed scenarios should be interpreted as illustrative experimental instances rather than a closed design set. Additional symbolic combinations (for example, high Justice + high Resistance or high Hope + high Eco-symbiosis) can be generated using the same symbolic encoding logic depending on specific research objectives.
4. Symbolic intensity encoding rule. To improve reproducibility, NTM node intensities are defined using a three-level symbolic scale:
   - Low → symbolic features minimally present.
   - Medium → symbolic features moderately present.
   - High → symbolic features strongly emphasized.

These levels are operationalized through spatial design features such as:

- Visibility
- Openness
- Material expression
- Spatial hierarchy
- Environmental integration

This encoding allows independent researchers to replicate symbolic manipulations.

5. Reproducible scenario generation logic

Scenario construction follows the symbolic inference chain described previously:

$$\text{NTM node definition} \rightarrow \text{symbolic intensity assignment} \rightarrow \text{spatial feature encoding} \rightarrow \text{VR scenario implementation}$$

This structured pipeline ensures that symbolic environments can be systematically reproduced and extended.

To ensure reproducibility, scenario construction follows explicit symbolic encoding rules rather than intuitive spatial design decisions. This transforms scenario development into a structured experimental design process consistent with hypothesis-driven VR research methodologies.

5.3.2 Scenario construction rationale

The scenario profiles proposed in this work are not intended to represent an exhaustive factorial combination of all NTM nodes, but rather a set of controlled conceptual contrasts designed to illustrate how symbolic configurations can be experimentally manipulated within the NTA framework.

The selection of profiles follows three design principles.

5.3.2.1 Symbolic contrast principle

Scenarios were constructed to maximize perceptual contrast between symbolic conditions (for example, high Justice vs. low Hope) in order to facilitate detection of symbolic–emotional effects in exploratory validation studies.

5.3.2.2 Experimental feasibility principle

A full factorial design including all possible NTM node combinations would produce a large number of scenarios, potentially increasing participant fatigue and reducing experimental control. Therefore, the framework proposes a limited set of representative profiles suitable for pilot testing.

5.3.2.3 Framework extensibility principle

The proposed scenarios should be interpreted as illustrative examples rather than a closed set of experimental configurations. Other combinations (for example, high Justice + high Resistance) can be generated using the same symbolic encoding logic depending on specific research questions. To ensure reproducibility, scenario construction follows the symbolic inference chain described previously, where NTM node intensities are translated into spatial design parameters using explicit symbolic encoding rules.

5.4 Measures and data collection

To test the relationships proposed in NTA, three main classes of measures are envisaged.

5.4.1 Symbolic–emotional self-report (NTM questionnaire)

After each scenario, participants would complete a short NTM-based questionnaire including items for:

- Justice, Identity, Hope, Resistance, Eco-symbiosis,
- and possibly general affective states (e.g., comfort, tension, engagement).

Items can be Likert-type (e.g., 1–7) and structured to allow neutrosophic decomposition:

- Positive items (affirmation of a symbolic quality),
- Negative items (denial),
- Items probing ambiguity or mixed feelings.

From these responses, per scenario and per node, T–I–F components (truth, indeterminacy, falsity) can be derived.

5.4.2 Biofeedback signals (EEG, GSR, HRV)

During exploration of each scenario, the following signals would be recorded:

- EEG (e.g., frontal and parietal leads, or a low-density wearable device),
- GSR (skin conductance) as an index of autonomic arousal,
- HRV (heart rate variability) as an indicator of autonomic regulation and stress.

Signals would be:

- continuously recorded across scenarios,
- time-stamped and synchronised with VR events (e.g., entering/exiting symbolic zones, scenario start/end).

The aim is not to impose a specific hardware brand, but to ensure that sampling rates and pre-processing follow established psychophysiological guidelines.

5.4.3 VR interaction logs

The VR engine would log:

- Navigation trajectories (position over time),
- Time spent in predefined symbolic zones (e.g., areas strongly associated with justice or identity),
- Optionally gaze or head orientation, if available,
- Interaction events (e.g., inspection of symbolic elements, activation of features).

These logs provide behavioural features that complement physiological and self-report data.

5.5 Experimental procedure

A typical session could follow the steps below:

1. Briefing and consent
   - Explanation of study aims and procedures.
   - Informed consent and basic demographic questionnaire.
2. Setup and baseline
   - Fitting of EEG, GSR and HRV sensors, and VR headset.
   - Short baseline period in a neutral VR environment (e.g., simple empty room) to record resting-state signals.
3. Scenario exploration
   - Participants are exposed to each symbolically encoded scenario (e.g., 3–7 min per scenario).
   - Instruction: "Explore the space freely and pay attention to how it feels and what it expresses to you."
   - Scenario order is counterbalanced; short breaks can be provided to reduce fatigue.
4. Post-scenario evaluation
   - Immediately after each scenario, participants complete the NTM questionnaire referring specifically to that environment.
   - Optional: one or two open-ended questions about perceived meanings or narratives.
5. Debriefing
   - Removal of sensors, explanation of research context, and opportunity for participants to provide feedback.

Total duration per participant would typically be 60–90 min including setup and debriefing.

To illustrate how symbolic and physiological variables can be jointly analysed within NTA, we trained a simple Random Forest regressor to predict a synthetic "symbolic engagement" index based on both scenario-level NTM nodes and biofeedback features. The detailed numerical results of the feature importance analysis are presented in Table 5, while Figure 5 summarises the resulting feature importance profile. In this synthetic example, the symbolic dimensions of Resistance, Hope and Justice emerge as the most influential predictors of Justice_T, followed by HRV Mean and EEG Alpha, whereas Identity and Eco-Symbiosis play a comparatively smaller role. Although no empirical claim is made from these simulated values, the pattern demonstrates that the NTA pipeline can be used to quantify the relative contribution of symbolic and

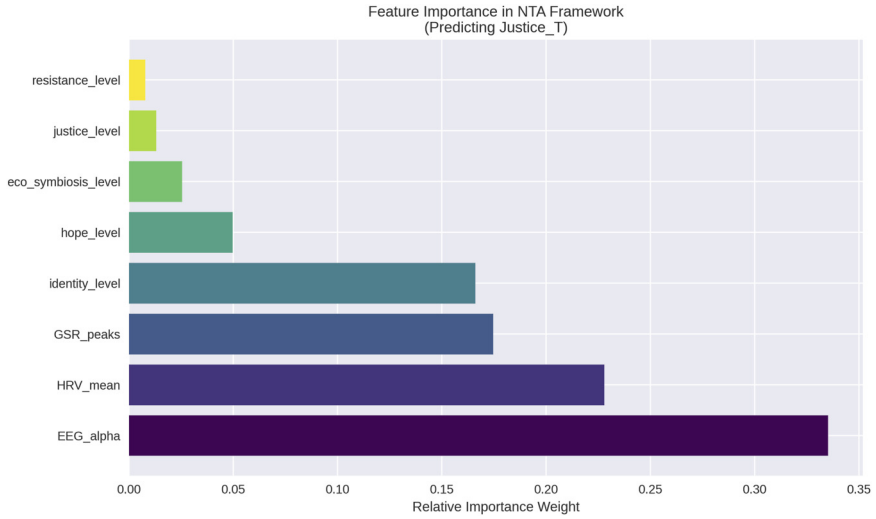

FIGURE 5
Synthetic feature importance profile in the Neutrosophic Technarrative Architecture (NTA). Horizontal bar plot showing the relative importance weights of scenario-level symbolic variables (Justice, Identity, Hope, Resistance, Eco-Symbiosis) and biofeedback features (HRV Mean, GSR Peaks, EEG Alpha) when predicting the neutrosophic Truth component of the Justice node (Justice_T) using a Random Forest regressor. All values are derived from synthetic data and are reported for illustrative purposes only, to demonstrate how symbolic and physiological variables can be jointly integrated and interrogated within the proposed NTA pipeline.

physiological components to neutrosophic evaluations of virtual spaces.

5.6 Analytical strategy and AI models

The blueprint for data analysis is aligned with the research questions and the NTA pipeline:

1. Pre-processing and feature extraction
   - Physiological data: filtering, artefact removal, extraction of features such as EEG band power, GSR peaks, HRV time and frequency indices.
   - Behavioural data: computation of dwell time in symbolic zones, path length, navigation entropy, interaction counts.
   - Self-report: computation of NTM node scores and transformation into T–I–F neutrosophic components.
2. Testing RQ1 and RQ2 (symbolic design ↔ self-report ↔ physiology)
   - Use repeated-measures ANOVA or mixed models to examine how symbolic conditions (NTM node intensities) affect self-reported evaluations and physiological indicators.
   - Correlation/regression analyses between symbolic profiles, T–I–F components and physiological features.
3. Testing RQ3 (integrated AI models)
   - Construction of supervised learning models to predict symbolic–emotional evaluations (e.g., T–I–F for each node) from:
     a. Symbolic design variables alone,
     b. Design + physiological features,
     c. Design + physiology + behavioural features.
   - Candidate models include:
     a. Regularised regression (e.g., LASSO, ridge),
     b. Tree-based methods (random forests, gradient boosting),
     c. Simple neural networks when sample size permits.
   - Performance comparison using cross-validation and metrics such as RMSE, MAE or classification accuracy, depending on the outcome format.
4. Testing RQ4 (added value of neutrosophic representation)
   - Comparison between models trained on classical scalar scores vs. neutrosophic T–I–F components:
     a. Differences in explained variance,
     b. Robustness to noisy or ambiguous responses,
     c. Interpretability of results for design decisions.
5. Interpretive synthesis
   - Qualitative–quantitative integration of findings to identify:
     a. Which symbolic configurations (NTM profiles) are associated with particular physiological and experiential patterns,
     b. How ambiguity (high I) manifests across scenarios and users,
     c. Implications for future VR-neuroarchitecture studies and design practice.

This methodological blueprint shows that the NTA is not merely a conceptual proposal, but a fully operational, testable framework. Different research teams can instantiate it with their own VR platforms, sensors and architectural scenarios, while preserving the core logic: explicit symbolic encoding (NTM), immersive VR exposure, multimodal data collection, neutrosophic representation of evaluations and AI-based integration of design, physiology and behaviour. At the group or stakeholder level, the neutrosophic evaluations generated within NTA can be further aggregated and compared using the multiperspectivist procedures validated in the Technarrative Model (NTM), including similarity, alliance and

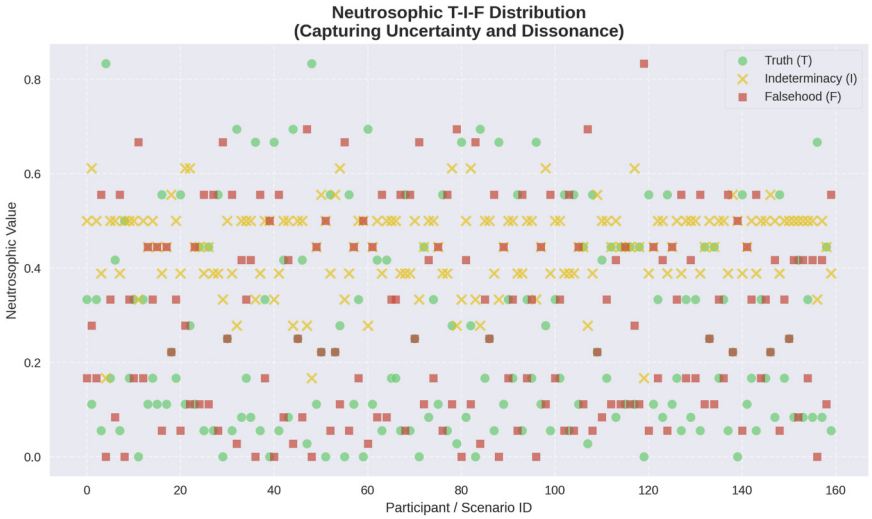

FIGURE 6
Neutrosophic T–I–F distribution for the Justice node in the synthetic NTA pipeline. Scatter plot of the neutrosophic Truth (T), Indeterminacy (I) and Falsity (F) components derived from Likert-type responses to Justice items across all synthetic participant–scenario pairs. Each point represents one evaluation instance. The plot illustrates how the framework separates strong symbolic agreement (high T), ambiguous or conflicting appraisals (I) and residual disagreement (F). All values are based on simulated data and are shown solely as an example of how the proposed NTA model can be operationalised.

TABLE 6 **Sample neutrosophic T–I–F mappings for Justice and Identity nodes across representative participant–scenario combinations in the synthetic NTA pipeline.**

ID	Scenario	justice_T	justice_I	justice_F	identity_T	identity_I	identity_F
P01	S1	0.333	0.5	0.166	0.222	0.556	0.222
P01	S2	0.111	0.611	0.278	0.556	0.389	0.056
P01	S3	0.333	0.5	0.167	0.111	0.444	0.444
P01	S4	0.056	0.389	0.556	0.167	0.5	0.333
P02	S1	0.833	0.167	0.0	0.083	0.5	0.417

polarization analyses among perspectives (Hechavarría-Hernández et al., 2025). This opens a path for future studies that combine individual-level VR biofeedback experiments with multi-stakeholder negotiations around virtual design proposals.

Once neutrosophic triads are computed for each participant–scenario combination, their distribution can be inspected at the level of individual nodes. Figure 6 shows an example for the Justice node, where each point corresponds to one synthetic evaluation instance. The neutrosophic mapping reveals a cluster of cases with high T (symbolic agreement), a band of moderate I (capturing ambiguity and dissonance between positive and negative items), and a smaller set of evaluations characterised by higher F. This illustrates how NTA moves beyond single scalar scores by explicitly representing the balance between endorsement, disagreement and indeterminacy in the appraisal of symbolic architectural constructs.

Table 6 presents a subset of the resulting neutrosophic triads for Justice and Identity in the first five synthetic participant–scenario combinations, showing how NTA decomposes each symbolic evaluation into its Truth, Indeterminacy and Falsity components.

5.7 Computational feasibility

To demonstrate the operational readiness of the NTA framework, a Python-based proof-of-concept is provided as Supplementary Material. This script simulates the integration of biometric signals and subjective reports, processing them through neutrosophic algorithms to yield T, I, F values. This demonstrates that the symbolic-emotional dimensions described (e.g., Justice, Hope) are computationally measurable and ready for empirical validation.

6 Discussion and theoretical implications

The NTA framework is designed to be realistically implementable using currently available technologies including commercial VR headsets, standard game engines, and widely used biometric sensors. All components required for implementation (VR modelling, physiological monitoring, AI analysis) are already widely used in experimental VR research.

Therefore, NTA should be understood not as a speculative proposal but as an integrative research architecture combining existing technologies within a unified symbolic evaluation framework. Future empirical work can directly implement this blueprint without requiring technological development beyond current research capabilities. Beyond its practical feasibility, NTA also raises important theoretical implications for VR research, neuroarchitecture, and computational design, which are discussed in the following sections.

6.1 Expanding the concept of presence

The Neutrosophic Technarrative Architecture (NTA) is intended not only as a technical integration of VR, biofeedback, and AI, but as a theory-driven re-framing of how symbolic–emotional experience in architectural spaces can be studied. This section summarizes its expected advantages and theoretical implications, particularly in comparison with:

a. UX-only questionnaires,
b. Purely technical VR pipelines, and
c. Probabilistic models without neutrosophic representation.

By combining symbolic encoding, multimodal measurement and neutrosophic representation within a single architecture, NTA contributes to several ongoing debates:

- In VR user experience research, it argues for a shift from general affect and usability towards structured, ethically loaded constructs (justice, identity, hope) as primary objects of study.
- In neuroarchitecture, it proposes a bridge between neuroscientific measures and architectural theory, using symbolic nodes as mediators between brain/body responses and design intent.
- In computational design and AI, it illustrates how explainable, symbolic features (NTM nodes) can be integrated with data-driven models to support reflective and responsible design, rather than purely optimising engagement or efficiency.

Overall, the expected advantage of NTA is not only to improve prediction or measurement, but to foster a more conceptually grounded, ethically aware and epistemically honest approach to studying and designing virtual architectural spaces.

6.2 Beyond UX-only questionnaires

A large body of VR research in built environments relies primarily on self-report instruments (e.g., presence, comfort, satisfaction, generic affect scales). While these are valuable, they exhibit several limitations:

- They often treat user experience as a single-layer construct (e.g., "pleasantness") without distinguishing between ethical, symbolic or narrative dimensions.
- They are typically collected after the VR experience, which can blur fine-grained temporal relations between specific spatial events and emotional responses.
- They do not explicitly represent internal conflict or ambiguity (e.g., feeling both inspired and threatened by the same space).

NTA addresses these limitations by:

1. Embedding questionnaires within a symbolic model (NTM)
   - Items are not generic UX descriptors, but are directly tied to symbolic nodes (justice, identity, hope, resistance, eco-symbiosis).
   - This allows researchers to ask not only "Is this space comfortable?" but also "Does this space feel fair?", "Does it support a sense of belonging?", "Does it evoke future-oriented hope?"
2. Linking self-report to multi-modal data
   - Self-reported evaluations are analysed alongside physiological and behavioural features, enabling richer interpretations (e.g., a scenario may be verbally described as "calm" but show elevated arousal in biofeedback).
3. Representing responses neutrosophically (T–I–F)
   - The neutrosophic decomposition of evaluations (truth, indeterminacy, falsity) allows UX data to capture ambivalence and uncertainty, rather than compressing them into a single score.

Theoretically, this shifts the focus from UX as a purely subjective, monolithic rating to UX as a multi-layered, symbolically structured and ambiguously held experience.

6.3 Beyond purely technical VR pipelines

Many VR studies in architecture and built environments emphasize technical aspects: fidelity of rendering, interaction mechanics, navigation techniques, or optimization of performance and latency. These contributions are crucial, but they tend to treat human response as a secondary validation step or a generic "user test." In contrast, NTA places symbolic–emotional response at the center of the pipeline and treats technical VR implementation as a means to achieve a theory-driven end.

1. Symbolic encoding as a first-class design input
   - Scenarios are constructed to instantiate specific symbolic profiles grounded in the Neutrosophic Technarrative Model (NTM).
   - This supports hypothesis-driven design: VR scenarios are crafted to manipulate particular symbolic configurations (e.g., high vs. low Justice).
2. Biofeedback and behaviour as interpretive data, not just biomarkers
   - Physiological data are not used merely to prove immersion, but to explore how symbolic narratives are embodied.
   - Evidence confirms that specific architectural elements—such as aspect ratios, ceiling heights, and window ratios—produce statistically significant variations in psychophysiological markers, such as the Relaxation-Arousal Response (RAB) measured via EEG (Kim et al., 2021).
   - Under NTA, we transcend simple arousal measurement; we interpret these neurophysiological signatures as the

materialization of symbolic intent: whether spaces intended as "protective" effectively reduce autonomic arousal relative to spaces intended as "dominating."

3. VR as an experimental laboratory for architectural meaning
   - Under NTA, VR is conceptualized as a symbolic laboratory where hypotheses about justice, identity, or hope in architecture can be experimentally manipulated under controlled conditions.
   - By aligning design parameters (e.g., spatial volume) with neuro-computational outcomes, we move beyond purely technological validation toward a computationally supported architectural theory.

Theoretically, this situates VR research within a broader discourse on architectural meaning, where the environment is no longer just a backdrop for interaction, but a calibrated stimulus capable of inducing structured cognitive-emotional states.

6.4 Beyond purely probabilistic models: the role of neutrosophic representation

Most quantitative analyses in VR and UX adopt classical or fuzzy probabilistic models: user evaluations are treated as single numerical values, and uncertainty is implicitly captured through variance or confidence intervals. While powerful, this approach has limitations for symbolic–emotional assessment:

- It assumes that each judgment can be adequately summarised by one number (e.g., 5/7), even when users are internally conflicted.
- It does not distinguish between low agreement due to genuine disagreement and low agreement due to indecision or lack of clarity.
- It encourages a search for clear-cut, monotonic relationships (e.g., "more X leads to more Y"), even when symbolic responses may be non-monotonic, context-dependent and contradictory.

NTA incorporates neutrosophic logic to explicitly represent.

- T (truth) – the degree of support for a statement (e.g., "this space is just"),
- I (indeterminacy) – the degree of uncertainty, ambivalence or mixed feelings,
- F (falsity) – the degree of rejection of that statement.

This has several expected advantages.

1. Richer modelling of subjective experience
   - A user who is strongly convinced that a space is unjust (high F, low T, low I) is different from someone who is uncertain (moderate T, moderate F, high I), even if both produce similar average scores on a classical scale.
2. Better alignment with complex design questions
   - Architectural decisions often involve conflicting criteria and stakeholders; neutrosophic measures mirror this complexity by allowing partial and even contradictory evaluations to coexist.
3. Improved interpretability in AI models

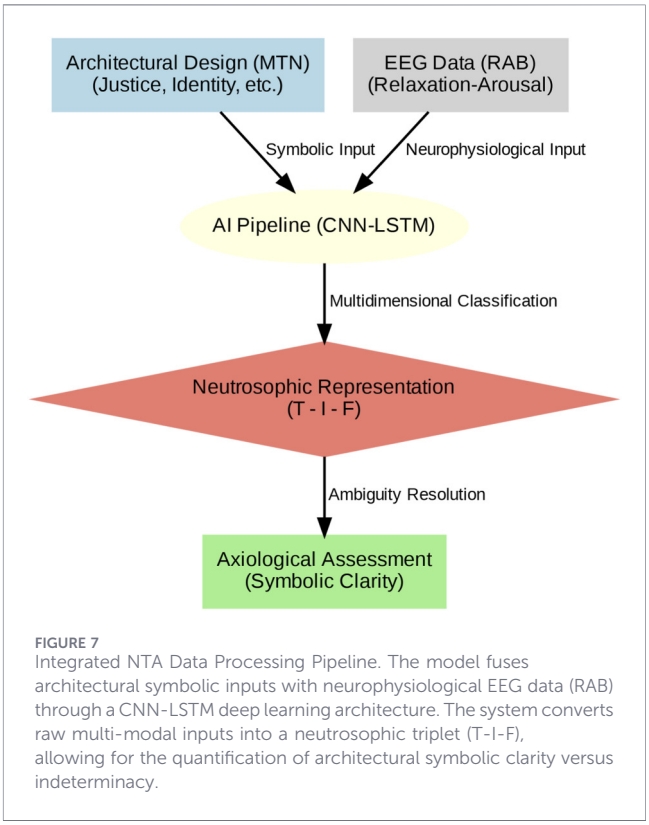

FIGURE 7
Integrated NTA Data Processing Pipeline. The model fuses architectural symbolic inputs with neurophysiological EEG data (RAB) through a CNN-LSTM deep learning architecture. The system converts raw multi-modal inputs into a neutrosophic triplet (T-I-F), allowing for the quantification of architectural symbolic clarity versus indeterminacy.

   - When AI models are trained to predict T–I–F components, designers can see:
     a. Which spatial features increase perceived justice (T),
     b. Which features reduce indeterminacy (I) (i.e., clarify meaning),
     c. And which features trigger rejection (F) of certain symbolic qualities.
   - This provides a more nuanced basis for design decisions than predicting a single scalar rating.

In theoretical terms, NTA proposes that symbolic–emotional responses are inherently neutrosophic—they often involve simultaneous degrees of belief, doubt and disbelief. Building upon the foundations of neutrosophic set theory as a generalization of fuzzy sets (Smarandache, 2019) and following recent advancements in neutrosophic explainable AI for modeling behavioral indeterminacy in high-stakes immersive VR simulations (Hechavarria-Hernandez, 2026), our framework elevates this inherent ambivalence from mere statistical "noise" to a central epistemic resource for understanding how people relate to architectural narratives in VR. The integration of NTA symbolic nodes (Justice, Identity, Hope, Resistance, Eco-symbiosis) shifts the paradigm of virtual architectural evaluation. By treating these nodes not merely as subjective perceptions but as axiological constructs, we acknowledge that architectural space is never neutral. This framework elevates the design process from mere technical optimization to a value-based practice, ensuring that the digital architecture of the future remains human-centric and ethically grounded.

The necessity of this approach is further underscored by the neurophysiological complexity of human-environment interactions. Recent studies have empirically verified that specific variations in architectural elements—such as ceiling height or spatial ratios—elicit statistically significant shifts in relaxation-arousal responses, detectable through EEG markers like the Relaxation-Arousal Response (RAB) (Kim et al., 2021). However, such data is often interpreted through a reductionist lens that ignores the subjective depth of the architectural experience.

By applying neutrosophic logic, we bridge the gap between neurophysiological response and symbolic experience. Rather than dismissing response variability as statistical "noise," we elevate "indeterminacy" (I) to a core epistemic variable. This process, visualized in Figure 7, establishes a systematic inference mechanism that translates raw multi-modal inputs into a structured axiology.

Specifically, the pipeline integrates physiological markers (such as the Relaxation-Arousal Response, RAB) with spatial configuration data to compute a neutrosophic triplet (T-I-F). In this model, the Truth (T) component represents the degree of alignment between the intended symbolic node and the user's neurophysiological state; the Indeterminacy (I) component quantifies the neural and cognitive hesitation—or "symbolic ambiguity"—elicited by the environment; and the Falsity (F) component captures the degree of cognitive-emotional dissonance. This inference mechanism serves as a bridge, converting complex, raw physiological data into an intelligible "axiological signature" that provides architects with actionable insights into the symbolic performance of their designs.

Through this model, we can decode why certain environments—while technically optimized for comfort or arousal—may fail to communicate their intended symbolic load. In this sense, the neutrosophic representation allows us to distinguish between mere technical effectiveness (arousal control) and true symbolic clarity (axiological resonance). Ultimately, this framework shifts the architectural evaluation paradigm: by treating symbolic nodes not merely as subjective perceptions but as axiological constructs, we provide designers with a precise instrument to identify where architectural narratives become unclear, contradictory, or emotionally inaccessible to the user, ensuring that digital architectural space remains a deliberate instantiation of human values.

6.5 Conceptual novelty of NTA

While the technological components used in NTA (VR environments, physiological sensing, and AI analysis) are individually well established in affective computing and Kansei engineering research, the novelty of this work does not reside in these technologies themselves. Instead, the primary contribution of NTA lies in three integrative advances:

- The introduction of symbolic–axiological architectural nodes as measurable constructs.
- The formalization of symbolic interpretation through neutrosophic logic to represent ambiguity and interpretative uncertainty.
- The integration of symbolic meaning, physiological response, and AI analysis into a unified research architecture.

Thus, NTA should be understood not as a technological innovation but as a conceptual and methodological innovation that reorganizes existing technologies into a new scientific evaluation paradigm.

7 Limitations and future work

Although the Neutrosophic Technarrative Architecture (NTA) is designed as a testable framework, its current form, as presented in this Hypothesis and Theory article, has several limitations that future empirical work should address.

7.1 Conceptual and scope-related limitations

First, NTA is introduced here as a conceptual and methodological proposal without empirical validation. While the framework is grounded in existing literature on VR, neuroarchitecture, biofeedback and neutrosophic logic, its actual performance—both in terms of predictive accuracy and practical usefulness—remains to be demonstrated. Future studies should implement the methodological blueprint outlined in Section 5 and systematically test the proposed hypotheses (H1, RQ1–RQ4) in real experimental settings.

Second, the current formulation of the NTM node set (justice, identity, hope, resistance, eco-symbiosis) reflects a particular emphasis on ethical, social and environmental dimensions of architecture. This is both a strength and a limitation: it foregrounds normative concerns often overlooked in VR UX research, but may not cover other relevant symbolic domains (e.g., safety, community, spirituality, playfulness). Future work could extend or adapt the node taxonomy for different building typologies, cultural contexts or research questions, while preserving the general NTA logic.

7.2 Methodological and technical constraints

Third, the methodological blueprint assumes access to specialized VR hardware, high-fidelity biofeedback sensors (EEG, GSR, HRV), and significant technical expertise to manage the integration of these multi-modal streams. In practice, resource constraints may limit sample sizes, signal quality, or the complexity of the architectural scenarios deployed. Furthermore, the integration of deep learning architectures (e.g., CNN-LSTM) requires large, high-quality datasets to ensure model robustness. Early implementations of NTA may need to begin with simplified setups—such as utilizing a single physiological channel or constrained scenario sets—and progressively scale up as infrastructure and technical expertise grow. Comparative studies using diverse sensor arrays and data pipelines will be essential to assess the generalizability of the NTA framework across different technological ecosystems.

Fourth, psychophysiological measures are inherently noisy and highly context-sensitive. Motion artifacts, individual differences in baseline arousal, mental fatigue, and extraneous non-architectural variables (e.g., personal stressors) can significantly influence EEG, GSR, and HRV signals. While standardized pre-processing and quality control procedures can mitigate these disturbances, they cannot entirely eliminate them. To address this, future research should prioritize multi-session longitudinal designs, larger and more heterogeneous population samples, and the integration of complementary sensing modalities—such as eye-tracking or facial expression analysis—to achieve a more robust triangulation of emotional and cognitive states. Additionally, the development of open-source synthetic datasets will be critical to support the training and validation of the NTA data processing pipeline, lowering the barrier to entry for other research teams.

7.3 Representational and interpretive challenges

Fifth, while neutrosophic representation (T–I–F) is conceptually well-suited to model human-environment ambivalence and partial belief, it introduces additional complexity into survey design, data processing, and result interpretation. Researchers must carefully define how traditional quantitative inputs—such as Likert-type scales, mixed-item patterns, or qualitative open-ended responses—are mapped to the Truth (T), Indeterminacy (I), and Falsity (F) components. These mappings require rigorous empirical validation to ensure that the mathematical output remains grounded in actual user experience. Furthermore, there is a risk that the added mathematical sophistication might hinder broader adoption within the architectural community if not supported by clear, standardized guidelines and accessible tooling, such as open-source scripts, templates, and annotated Jupyter notebooks, as provided in this study.

Sixth, the interpretive power of the NTA framework depends heavily on how precisely symbolic encoding is specified. The mapping from abstract NTM nodes to concrete design features is inherently cultural and context-dependent; different expert groups or cultural populations may legitimately disagree on whether a particular spatial configuration qualifies as "high in justice" or "high in hope." While this inherent subjectivity cannot be entirely eliminated, it should not be viewed as a flaw. Instead, future work can address this through structured expert panels, Delphi methods, inter-rater agreement studies, and cross-cultural comparisons. By doing so, the act of symbolic mapping itself is elevated from a design assumption to an object of systematic empirical investigation, allowing for the creation of a "cultural library" of symbolic-semantic mappings that can be integrated into future iterations of the NTA pipeline.

7.4 Relation to the technarrative model (NTM) and multiperspectivist extensions

The NTA framework can also be viewed as a natural continuation of the Technarrative Model (NTM) previously applied to a heritage building. Whereas NTM focused on multiperspectivist integration of expert and community judgments in a physical context, NTA emphasises individual experiential dynamics in virtual reality, enriched with biofeedback and interaction data. In future work, both approaches could be combined: VR scenarios designed under NTA could be presented to multiple stakeholder groups, and their neutrosophic evaluations (T–I–F) could be aggregated using the multiperspectivist machinery developed for NTM. This would enable the analysis of alliances, conflicts and uncertainty among groups exposed to the same symbolic virtual environments, creating a bridge between micro-level embodied responses and macro-level socio-symbolic negotiations in architectural and urban decision-making.

7.5 Future directions

Several lines of future work emerge from these limitations:

1. Proof-of-concept experiments
   - Implement small-scale studies (e.g., 30–40 participants, 3–4 VR scenarios, a subset of sensors) to test whether NTA can detect meaningful relationships between symbolic encoding, physiological patterns and neutrosophic evaluations.
2. Cross-cultural and cross-typology studies
   - Apply NTA to different cultural contexts (e.g., Latin America, Europe, Asia) and building types (schools, hospitals, public spaces), examining how NTM nodes and their design expressions vary while the framework structure remains stable.
3. Tool development and open resources
   - Develop open-source scripts, data schemas and example datasets that demonstrate how to implement NTA in practice (from scenario metadata to T–I–F computation and AI models), lowering the barrier to adoption for other research teams.
4. Integration with design workflows and education
   - Explore how NTA can be embedded into architectural and interior design studios, using VR and neutrosophic evaluation as pedagogical tools to reflect on justice, identity, hope and eco-symbiosis in student projects.
5. Multi-user and dynamic scenarios
   - Extend the framework from single-user explorations to social and multi-user environments, where symbolic meaning emerges not only from space itself but from interactions between users. This would open a path towards studying public space, participatory design and urban justice in VR.

In summary, the main limitation of the present work is that it offers a conceptual architecture rather than empirical proof. At the same time, this is precisely its contribution: by providing a structured, neutrosophic and symbolically grounded framework, NTA delineates a clear agenda for future research at the intersection of VR user experience, neuroarchitecture and ethically oriented architectural design.

8 Conclusion

This Hypothesis and Theory article has introduced the Neutrosophic Technarrative Architecture (NTA) as a

comprehensive framework for the symbolic–emotional evaluation of virtual architectural spaces. Rather than treating VR environments, biofeedback measurements, and user self-reports as independent analytical components, NTA proposes an integrated research architecture that connects the Neutrosophic Technarrative Model (NTM) with immersive VR scenarios, neurophysiological indicators, and a structured computational inference pipeline.

As a conceptual contribution, NTA reframes architectural experience in VR as a symbolically structured and inherently ambiguous phenomenon. By integrating neutrosophic logic, the framework elevates the indeterminacy (I) of user responses from a source of statistical noise to a central epistemic resource. This perspective enables the capture of cognitive dissonance, symbolic resonance, and affective ambiguity that conventional deterministic or purely statistical models often fail to represent. Importantly, the novelty of the proposed framework does not reside in the individual technological components employed—such as VR platforms, physiological sensing technologies, or machine learning techniques—which are already established within affective VR and neuroarchitecture research. Instead, the main contribution lies in the interpretive and modeling architecture that connects symbolic architectural meaning, uncertainty representation, and multimodal human response analysis within a unified scientific framework.

Methodologically, the study also contributes by strengthening reproducibility through explicit symbolic modeling rules, computational workflow transparency, and the provision of a structured symbolic node derivation protocol (Supplementary Appendix SA). These elements position NTA not merely as a theoretical proposal but as a reproducible research blueprint that can support future empirical validation studies. From a feasibility perspective, the framework is intentionally grounded in currently available technologies, allowing realistic experimental implementations without requiring novel hardware development. This design choice supports the role of NTA as a testable research hypothesis and a methodological foundation for future neuroarchitecture investigations.

Future research directions include empirical validation with larger participant cohorts, cross-cultural symbolic interpretation studies, integration with adaptive VR environments, expansion of symbolic node taxonomies, and the development of explainable AI models capable of interpreting symbolic–physiological relationships. These directions position NTA as a starting point for a broader research program at the intersection of symbolic architecture, immersive environments, and uncertainty-aware computational design. Overall, this work establishes a new research agenda that formalizes the symbolic dimension of architectural experience as a measurable and scientifically investigable construct. By bridging symbolic design theory, neurophysiological measurement, and computational uncertainty modeling, NTA contributes toward a more interpretable, reproducible, and human-centered paradigm for architectural evaluation in virtual environments.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

JRH-H: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. LV-C: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – review and editing. FS: Conceptualization, Supervision, Validation, Writing – review and editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This work was supported by Ecotec University through the institutional research project 2025IBAFIACN_007: “International Observatory of Symbolic Architecture (IOSA): Neutrosophic Technarrative Model for Architecture (NTM)”. The article processing charges (APC) were fully covered by Ecotec University. No external grants or third-party commercial funding were involved in the development of the neutrosophic framework, the simulation pipeline or the statistical analyses.

Acknowledgements

The authors gratefully acknowledge Ecotec University for its institutional support, research environment and computational infrastructure, which made this work possible. The authors also thank the University of New Mexico for its longstanding contribution to neutrosophic theory and its applications in decision science. These institutions supported the intellectual development of the Neutrosophic Technarrative Architecture (NTA), without direct financial involvement beyond the internal funding provided by Universidad ECOTEC.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2026.1818469/full#supplementary-material

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Nomenclature

NTA	Neutrosophic Technarrative Architecture (The overall framework)
NTM	Neutrosophic Technarrative Model (The node-based symbolic model)
T, I, F	Neutrosophic triplet: Truth (T), Indeterminacy (I), and Falsehood (F)
VR	Virtual Reality
EEG	Electroencephalography (measures brain electrical activity)
HRV	Heart Rate Variability (indicator of autonomic nervous system balance)
GSR	Galvanic Skin Response (measures skin conductance/arousal)
AI	Artificial Intelligence
Biofeedback	Real-time physiological data used as input for the system
Symbolic Node	A conceptual dimension of architectural meaning (e.g., Justice, Hope)
μ(x)	Membership function in neutrosophic sets
Axiological Depth	The degree of ethical and value-based meaning within a space
S_n	Virtual Scenario n (where n is the specific design iteration)
P_m	Participant m within the experimental study